



Indian Journal of Engineering

Analysis on Mechanical Properties of Al/TiB₂ MMCs and Validated for FEA with Different Mould Condition

Rajaravi C¹, Lakshminarayanan PR^{2*}

1. Research Scholar, Department of Manufacturing Engineering, Annamalai University, Chidambaram - 608002, Tamil Nadu, India.
2. Professor, Department of Manufacturing Engineering, Annamalai University, Chidambaram - 608002, Tamil Nadu, India

*Corresponding author: Department of Manufacturing Engineering, Annamalai University, Chidambaram - 608002, Tamil Nadu, India. E-mail: rajaravi.mech@gmail.com

Publication History

Received: 18 July 2016

Accepted: 13 August 2016

Published: October-December 2016

Citation

Rajaravi C, Lakshminarayanan PR. Analysis on Mechanical Properties of Al/TiB₂ MMCs and Validated for FEA with Different Mould Condition. *Indian Journal of Engineering*, 2016, 13(34), 634-645

Publication License



© The Author(s) 2016. Open Access. This article is licensed under a [Creative Commons Attribution License 4.0 \(CC BY 4.0\)](https://creativecommons.org/licenses/by/4.0/).

General Note



Article is recommended to print as digital color version in recycled paper.

ABSTRACT

Aluminum alloy A356/TiB₂ In-situ MMCS have been fabricated through salt metal reaction route. In this present study the A356 alloy reinforced with TiB₂ particle cast in permanent mould for different pouring temperatures, have showed that the mechanical properties (i.e. Fracture Toughness, Tensile Strength, Hardness) increased as compared to that cast in sand mould. Also, the

mechanical properties of composites were found to increase with pouring temperature up to 820 °C. The observation on SEM and XRD confirmed the formation of TiB₂ particulates. The experimental results validated the FEA results obtained through ANSYS 13. The predictions on mechanical properties using these models are in good agreement with experimental data for both sand mold and permanent mold with different conditions.

Keywords: Titanium-di-boride, Al/ TiB₂ MMC, mechanical property, FEA

Abbreviations: FEA – Finite Element Analysis, ANSYS-Analytical simulation

1. INTRODUCTION

Particulate Reinforced Metal Matrix Composites (PRMC) has received intensive interests due to their outstanding combination of mechanical properties. These properties make them potential candidates in aerospace, automotive and manufacturing field (Shashi Prakash Dwivedi., et al, 2014; Veereshkumar, G.B., et al, 2011; Ali MAZAHERY., Mohsen Ostad SHABANI., 2012; and Rabindra Behera., et al, 2012). PRMCs have been fabricated normally by conventional ex-situ process due to the ease of fabrication, lower cost and isotropic properties. The ex-situ composites are fabricated by directly adding reinforcement in to the matrix (Gaurav Chigal., Gaurav Saini., 2012 ; ZHANG Jun., et al, 2012; and Anuraj Singh., 2014). In this In-situ method, reinforcements are synthesized inside the metal by chemical reaction during formation of composite. In-situ MMCs attracted due to their advantages, such as well distributed fine reinforcement and good bonding between matrix and reinforcement (Niranjan, K., Lakshminarayanan, P.R., 2013; Nimbalkar, V.M., et al, 2011; Jinyong Zhang., et al, 2015; U. Athul Atturan., et al, 2016 ;Fei Chen., et al, 2015; Dhokey, N.B., et al, 2011; and Mingliang Wang., et al, 2014). Finite Element Analysis (FEA) is a numerical method of analysis for stress variation due to deformations in structure of any given geometry. FEA permits in considerable time shortening for project process and give the possibility to research the influence of each factors on the whole mathematical model and the simulation results are more reliable ad well approximately close to real values. ANSYS is a complete FEA software package used in engineering fields like structure, electric, mechanical and electromagnetic (Reddy, J.N., 2006).

In this study, the In-situ Al/TiB₂ composite were successfully synthesized through salt metal reaction route and the researcher has undertaken to study the mechanical properties both cast permanent mould and sand mould. For both the mould conditions the mechanical properties (i.e Fracture Toughness, Tensile Strength) were tested with different conditions of In-situ Al/TiB₂ composite and validated in FEA.

2. MATERIALS AND METHODS

The A356 alloy reinforced with constant 6 vol% TiB₂ particles were produced by adding the pre weighed mixed salts of Potassium Hexa Fluro Titanate (K₂TiF₆) and potassium tetra Fluro Borate (KBF₄) maintained at 250°C for about 30 minutes. These salts react exothermally in the melt. The melt was stirred using a blade paddle mixer for 30 min, and then the slag was skimmed out completely. After the reaction is complete, the melt was poured temperature into permanent and sand moulds obtain the cast ingots. For both permanent mould and sand mould cast ingots the mechanical properties, i.e., fracture toughness, tensile strength, hardness were evaluated the following:

1. Fracture toughness was experimentally found using Instron 8801 Dynamic testing machine. The test was continued until the Specimens failed ultimately due to unstable crack growth or fracture. Samples were fabricated according to ASTM standard E399.
2. Tensile specimens were prepared according to ASTM standard E8-03. In each casting two samples were tested. Tensile test was carried out in an electro-mechanically controlled universal testing machine.
3. The hardness tests were carried out by Brinell hardness testing machine and hardness values were tested with three replications. The average results obtained are taken for final values.
4. The TiB₂ particles in the composite were identified by an X-Ray diffractometer and morphology of the composites were characterized using Scanning Electron Microscopy.

3. FINITE ELEMENT ANALYSIS

FEA simulation of deformations during fracture toughness, tensile and hardness were used in ANSYS program.

ANSYS work methodology:

1. Apply material properties
2. Create the model as the practical experimental
3. Meshing is carried out as per the size control
4. Define the special conditions
5. Define load
6. Solve
7. Results

FEA for 3 point bend specimen is idealized by 4 node 182 elements. Only half of the specimen was modeled with appropriate boundary conditions on the plane of symmetry. The FE models initially formed with elastic material properties, $E = 94.2 \text{E}3 \text{ MPa}$ and $\nu = 0.33$, and a load P of 13 MPa and Mesh the 3PB specimen. The FEA model of tensile specimen is meshed with the plane 182 element obtained with 1616 nodes. The geometrical data input to the computer is taken from the tensile test configuration according to ASTM E8M-04 standards. One end of the specimen is fully restrained and the other end is constrained to have translations along the principal material direction. The computer simulations are performed by applying the load 100 kN and boundary conditions. FEA simulations of deformation during hardness test by Brinell method were made taking into consideration that real model is symmetric and model made in Ansys is $\frac{1}{4}$ of real model. The advantage of simulation with axis-symmetric condition is that the spherical ball is considered as a quarter circles only. The contact pair is created between indenter and sample. This investigation is carried out by ANSYS and the indenter and specimen both are meshed in this model. It is constrained to move in x and y directions along the nodes at bottom. Axisymmetry conditions are applied along the center line. The interaction of indenter and the specimen is modeled as contact pair with no friction. In simulation program the contact element was used in order to TARGET 169 for ball tip and CONTACT circle 175 for specimen. Mutli-linear isotropic hardening plasticity model is used to extract the plastic properties of the materials.

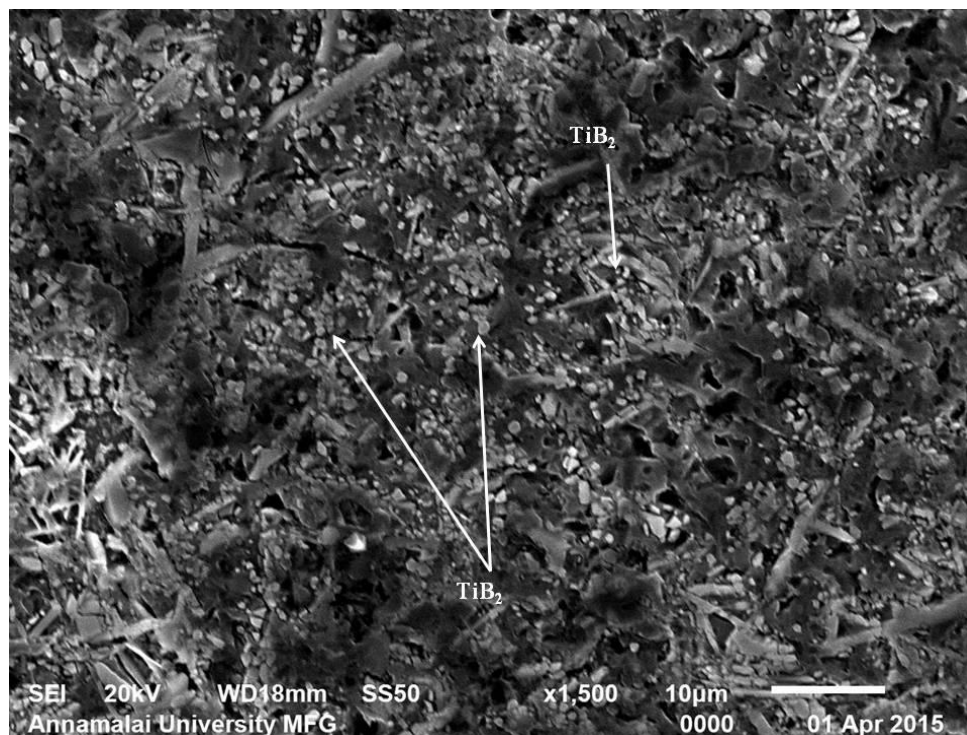


Figure 1

SEM micrograph shows Al/TiB₂ prepared 820°C (X 1500) at permanent mould

4. RESULTS AND DISCUSSION

4.1. Characterization of in-situ Al/TiB₂ composites

(Figure 1) shows SEM Micrographs of Al- 6 wt % TiB₂ composites (permanent mould) with different temperature. The TiB₂ particles were in homogenously dispersed with uniform distribution of reinforcement particles in the matrix phase is observed from SEM micrographs shown at lower magnification of 10µm. For castings fabricated at different levels of temperature particularly the casting were produced at 820°C temperature have more number of TiB₂ particles dispersed, with reduced common defects such as porosity. Similarly (Figure 2) shows sand mould casting SEM micrographs. TiB₂ particles have formed as evidenced by XRD both permanent and sand mould with different conditions as shown in (Figure 3 and Figure 4) After pouring as the cooling rate is low the TiB₂ particles grow in size affecting the mechanical properties (Rajaravi, C., et al, 2015; and Christy, T.V., et al, 2010).

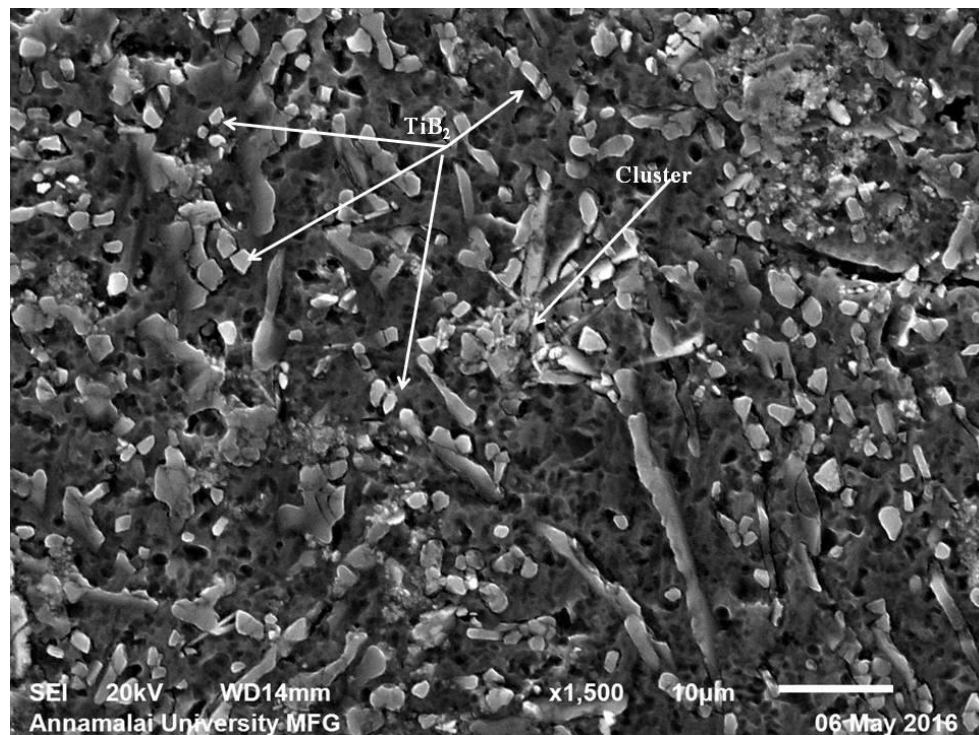


Figure 2

SEM micrograph shows Al/TiB₂ prepared 820°C (X 1500) at sand mould

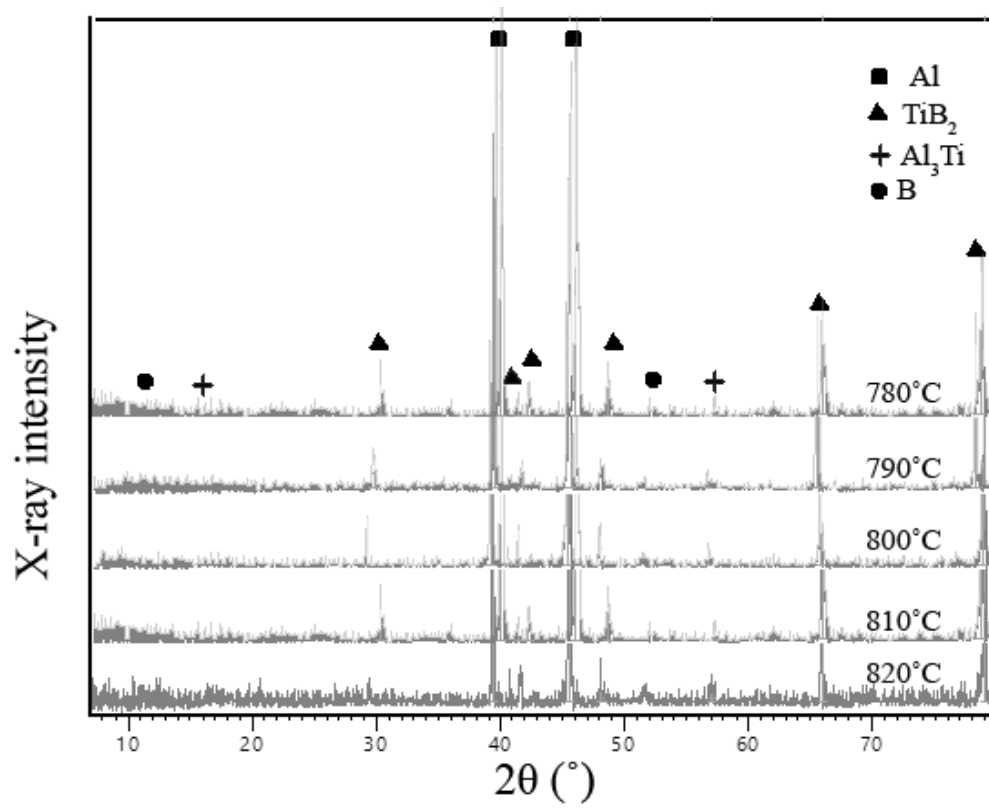


Figure 3

XRD spectra of in-situ Al/ TiB₂ composites show the permanent mould in 820°C

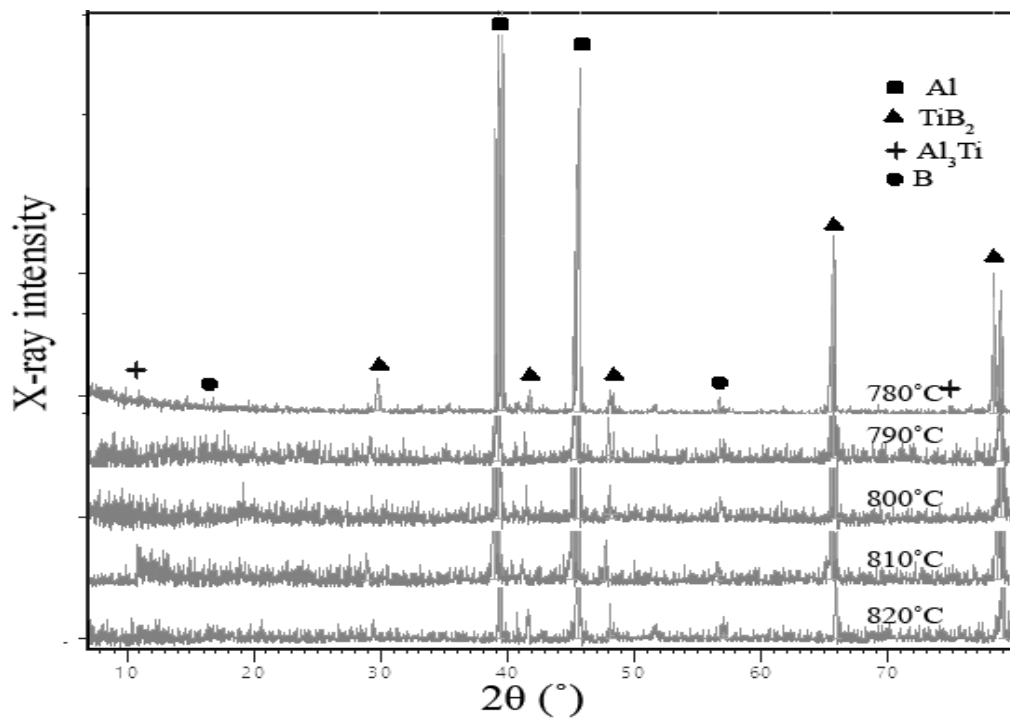


Figure 4

XRD graphs show the sand mould in 820°C

4.2. Fracture toughness of In-situ A356/TiB₂ composites

Table 1 show that the fracture toughness compared in sand and permanent mould conditions. It shows significant improvements of fracture toughness in permanent mould condition than sand mould. In permanent mould condition as the temperature increases fracture toughness K_{IC} also increases in range tested. In permanent mould condition the fracture toughness obtained is more as sand mould condition because of the finer grains obtained due to higher cooling rate in the permanent mould. Hence the results arrived at experimentally are almost matching the theoretically predicated fracture toughness value with 3 point bent specimen as shown in (Figure 5). Under mode I (crack-opening) loading K_I may be compared with a material's fracture toughness K_{IC} in order to predict the stability of a crack (Alaneme, K.K., Aluko, A.O., 2012; and Naresh.,S., et al, 2013). The fracture toughness was observed for different pouring conditions and at pouring temperature 820°C the highest toughness value was predicted theoretically and is 22.89 Mpa√m and the corresponding experimentally found value is 17.54 Mpa√m as shown in (Figure 6). Stress intensity factor error in the simulated model doesn't exceed 8 % as shown Table 2 the experimentally found values are lower because of the probable in the materials during fabrications.

Table 1

Tensile Strength, Hardness and Fracture toughness of Composite

S.No	Temperature °C	Tensile Strength (MPa)		Hardness (BHN)		Fracture toughness (Mpa√m)	
		Sand mould	Permanent mould	Sand mould	Permanent mould	Sand mould	Permanent mould
1	780°C	118	151	53.37	58.78	14.75	18.56
2	790°C	122	163	55.33	64.45	15.22	19.42
3	800°C	129	165	58.67	69.44	15.87	20.68
4	810°C	130	171	61.56	70.67	16.05	21.85
5	820°C	152	175	66.45	76.33	17.54	22.89

Table 2

Simulation and experimental values for Fracture Toughness of Al/TiB₂ MMCs

S.No	Temperature °C	Fracture Toughness (Mpa√m)					
		Sand Mould			Permanent Mould		
		EXP	FEA	Percentage of error	EXP	FEA	Percentage of error
1	780°C	14.75	15.86	6.9	18.56	19.45	4.5
2	790°C	15.11	16.65	9.2	19.42	20.56	5.5
3	800°C	15.87	17.87	11	20.68	22.47	7.9
4	810°C	16.75	18.56	9.7	21.85	23.21	5.8
5	820°C	17.54	19.89	11.81	22.89	24.35	5.9

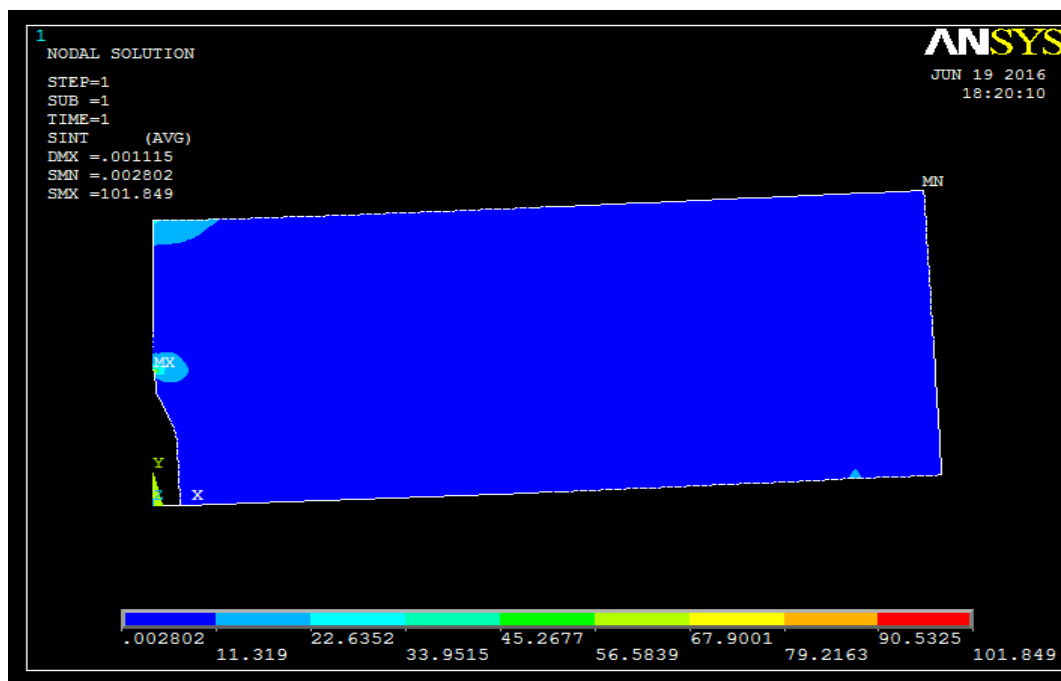
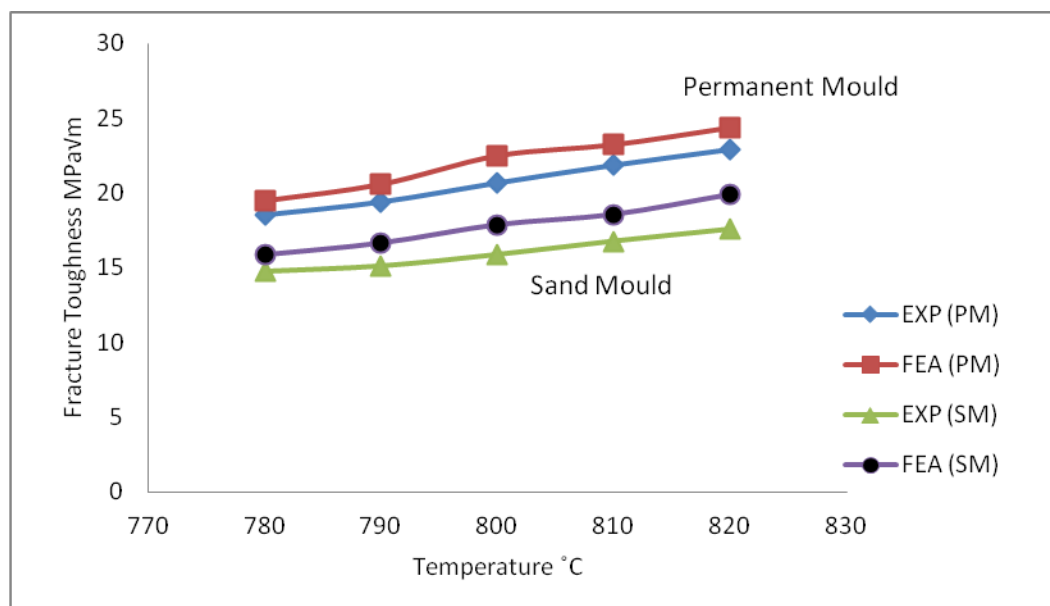
**Figure 5**

Image of the FE model simulating the 3PB test

**Figure 6**

Effect of processing temperature on fracture toughness of composite on FEA and Experimental results

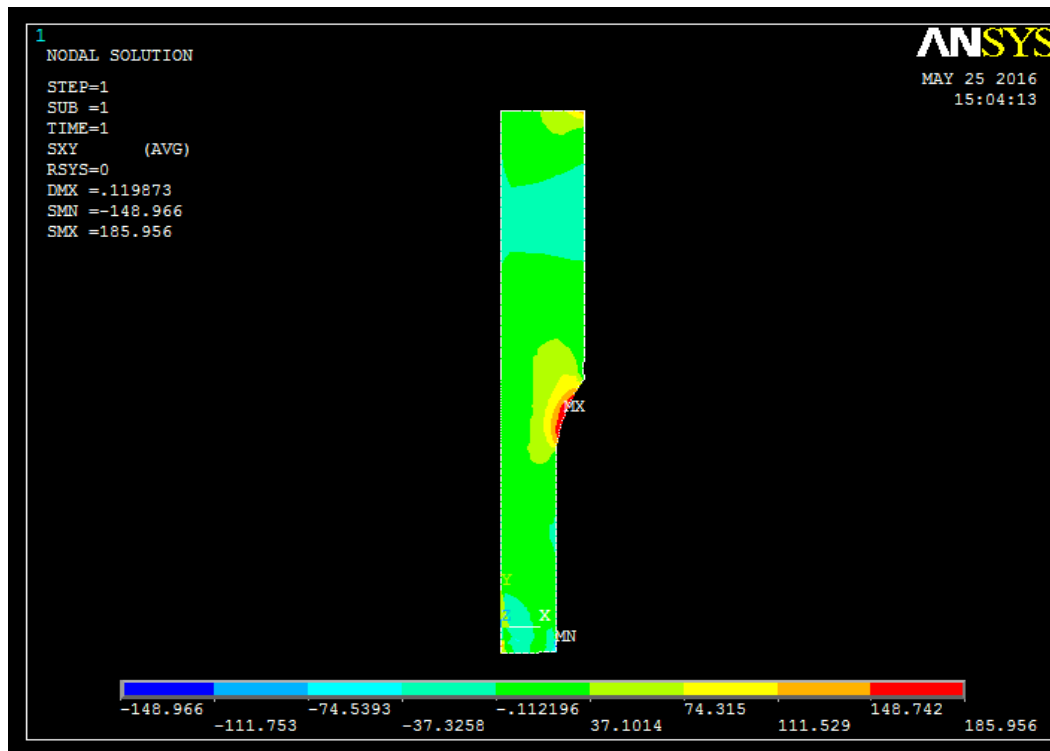
4.3. Tensile strength of In-situ A356/TiB₂ composites

The tensile strength distribution for the specimens of permanent mould and sand mould is shown in Table 1. For permanent mould casting UTS was observed to be more with higher temperature. As the cooling rate is high and TiB₂ particles formed are finer. In

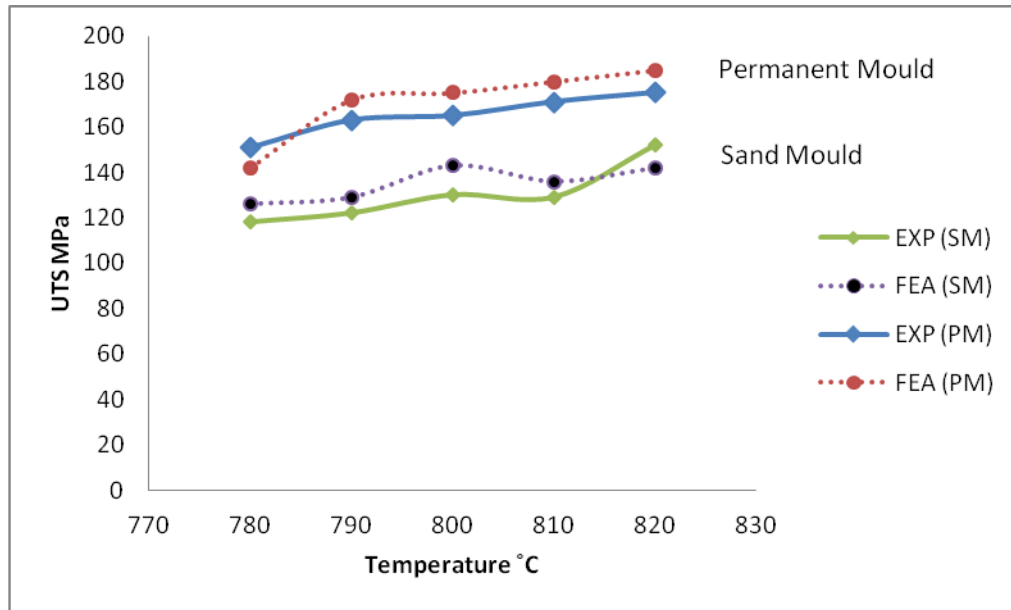
permanent moulds the tensile strength of the Al 6% wt of TiB_2 MMCs is increases from 151 MPa to 171 MPa as the pouring temperature increases from 780°C to 820°C . In sand moulds the tensile strength of the Al 6% wt of TiB_2 MMCs is increases from 118 MPa to 152 MPa as the pouring temperature increases from 780°C to 820°C . In permanent mould the tensile strengths are observed to be more as compared to sand molds as the grains formed are finer in permanent mould due to higher cooling rate as in (Figure 7). The experimentally are almost matching the theoretically predicated tensile strength value with tensile specimen as shown in (Figure 8). The experimental and FEA results are noticed to vary within 6 % as shown in Table 3 (Karbalaei Akbari, M., 2015).

Table 3Simulation and experimental values for Tensile Strength of Al/ TiB_2 MMCs

S.No	Temperature $^\circ\text{C}$	Tensile Strength (MPa)					
		Sand Mould			Permanent Mould		
		EXP	FEA	Percentage of error	EXP	FEA	Percentage of error
1	780°C	118	126	6.3	151	142	5.9
2	790°C	122	129	5.4	163	172	5.2
3	800°C	129	143	9.7	165	175	5.7
4	810°C	130	136	4.4	171	180	5
5	820°C	152	142	6.5	175	185	5.4

**Figure 7**

FE model of simulating the tensile test

**Figure 8**

Effect of processing temperature on tensile strength of composite on FEA and Experimental results

Table 4

Simulation and experimental value for hardness of Al/TiB₂ MMCs

S.No	Temperature °C	Hardness (BHN)					
		Sand Mould			Permanent Mould		
		EXP	FEA	Percentage of error	EXP	FEA	Percentage of error
1	780°C	53.37	62	13.9	58.78	69.75	15
2	790°C	55.33	64	13.5	64.45	74.40	13
3	800°C	58.67	63	6.8	69.44	76.80	9.5
4	810°C	61.56	69	10.78	70.67	79.40	10.9
5	820°C	66.45	72	7.7	76.33	86.76	12.

4.4. Hardness of In-situ A356/TiB₂ composites

The Brinell hardness test results are shown in Table 1. Both sand mould and permanent mould conditions as the temperature increases hardness also increases in range tested. On the basis of obtained simulation results, i.e., SMX, SMI, DMX, it was possible to compute the calculate hardness. The simulation hardness values were computed using Eqn. (1).

$$H_{\text{Brinell}} = N \times \text{SMX} \quad (1)$$

Where,

SMX - Max stress value obtained from ANSYS, N- Constant hitch value, depending on Ball indenter moving on block surface and is defined across different hitches.

Hardness results obtained with the help of max stress computer simulations as show (Figure 9). Error between predicted hardness and experimented values are less than 15% as shown Table 4 (Shivakumar Aradhya, K.S., Mrityunjay., Doddamani, R., 2015;and Śliwa,

Rajaravi C and Lakshminarayanan PR, Analysis on Mechanical Properties of Al/TiB₂ MMCs and Validated for FEA with Different Mould Condition, Indian Journal of Engineering, 2016, 13(34), 634-645,

A., et al, 2010). The hardness values obtained for permanent mould are more than sand mould s because finer grains as formed in permanent mold as the cooling rate are higher as in (Figure 10).

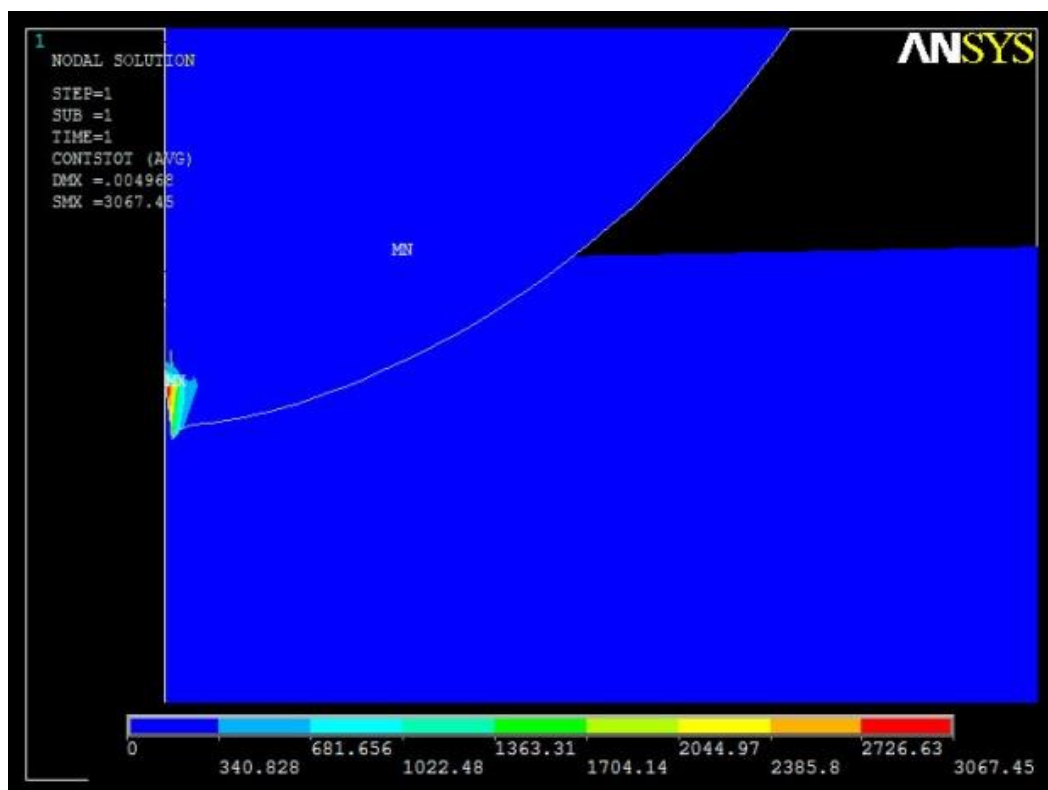


Figure 9

Image of the FE model simulating the Hardness test

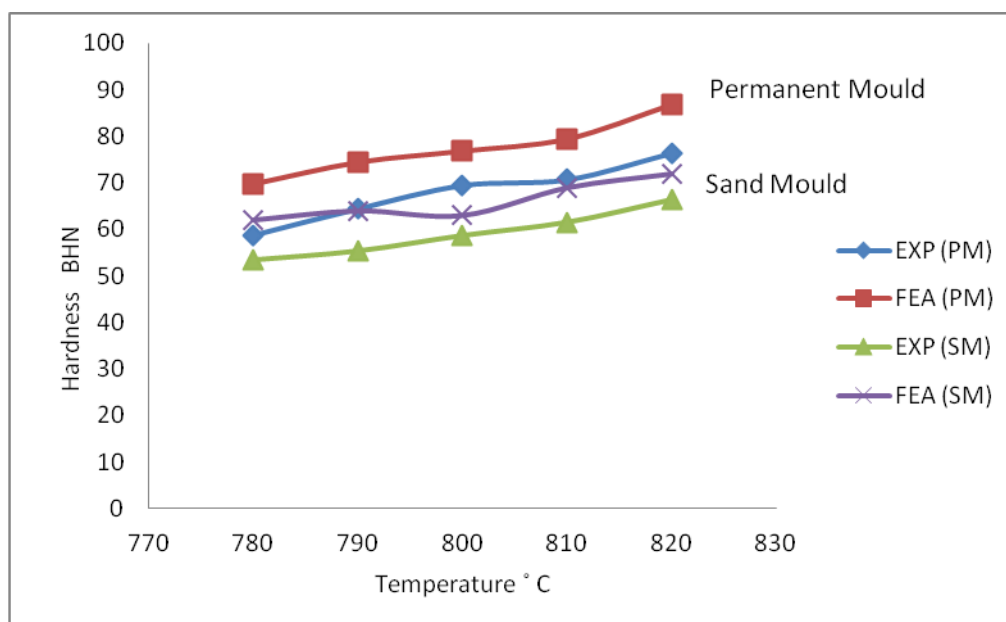


Figure 10

Effect of processing temperature on Hardness of composite on FEA and Experimental

Rajaravi C and Lakshminarayanan PR,
Analysis on Mechanical Properties of Al/TiB₂ MMCs and Validated for FEA with Different Mould Condition,
Indian Journal of Engineering, 2016, 13(34), 634-645,

5. CONCLUSION

Aluminium A356/TiB₂ was synthesized In-situ through the salt-metal reaction route and were analysed for ingots cast through both sand mould and permanent mould. TiB₂ particles have formed as evidenced by XRD and SEM both permanent and sand mould with different conditions. The results obtained in FEA exhibit a good agreement with the experimental finding

SUMMARY OF RESEARCH

- 1.Regarding the mechanical properties (i.e., fracture toughness, tensile strength and hardness) at permanent mould was increase with increase pouring temperature. Compared to sand mould and permanent mould the mechanical properties are found to be higher because in permanent mould finer grains are obtained.
- 2.The errors between the experimental and predicted of values are found to be less as follows: Fracture Toughness-8%, Tensile Strength-6%, Hardness-15%.

FUTURE ISSUES

I believe Different matrix composite may be cast as per sand mould and permanent mould may be characterized and based on the results obtained. It may be attempted to replace ZE41A magnesium and A356- Aluminium which are presently used in Aeronautical and Automotive applications.

DISCLOSURE STATEMENT

This work was financially supported by Rajiv Gandhi National Fellowship.

ACKNOWLEDGMENT

I am grateful to thank Annamalai Univeristy for providing the facilities for experimentation and, their constant support. We acknowledge useful discussions with Dr. K.Niranjan, Annamalai Univerity.

REFERENCES

1. Shashi Prakash Dwivedi., et all,A356 Aluminum Alloy and applications- A Review, Adv. Mater. Manu.Cha,2014, 4, 2.
2. Veereshkumar, G.B., et all. Mechanical and tribological behaviour of particulate reinforced Al metal matrix composites-a review, J. Min. mater. Cha.eng,2011, 8, 59-91
3. Ali MAZAHERY., Mohsen Ostad SHABANI.. Characterization of cast A356 alloy reinforced with nano SiC composites, Trans. Nonferrous Met. Soc, 2012, 22, 275–280
4. Rabindra Behera., et all. Distribution of SiC particulates in stir cast Aluminium alloy Metal matrix composites and its effect on mechanical properties, Int. J. Emer. trend. .Eng. Dev, 2012, 1, 2
5. ZHANG Jun., et all.Dispersion of SiC particles in mechanical stirring of A356-SiCp liquid, J. Cent. South Univ, 2012, 19, 1503–1507
6. Gaurav Chigal., Gaurav Saini. Mechanical testing Al6061/Silicon carbide metal matrix composites, Int. J. Res. Eng. Ap. Sci,2012, 2, 220-238
7. Anuraj Singh. Study of the Effect of Varying Pouring Rate on Mechanical Properties of Al-Cu and SiCp Reinforced Metal Matrix Composites (MMC), J. Ene. Tech. Pol, 2014, 4, 11
8. Niranjan, K., Lakshminarayanan, P.R.Optimization of process parameters for in situ casting of Al/TiB₂ composites through response surface methodology, Trans. Nonferrous Met. Soc, 2013, 23, 1269–1274
9. Mingliang Wang., et all. Mechanical properties of in-situ TiB₂/A356 composites, Mater. Sci. Eng A, 2104, 590, 246–254
10. Nimbalkar, V.M.,et all. Development reaction synthesis process of novel Al-alloys -TiB₂ metal matrix composites by in-situ, J. Met. Mater. Sci, 2011, 53, 197-203
11. Fei Chen., et all.TiB₂ reinforced aluminum based in situ composites fabricated by stir casting, Mater. Sci. Eng: A, 2015, 625, 357–368
12. Dhokey, N.B., et all. Effect of KBF₄ and K₂TiF₆ on precipitation kinetics of TiB₂ in aluminium matrix composite, Adv. Mat. Lett, 2011, 2(3) , 210-216
13. U. Athul Atturan., et all. Processing and characterization of in-situ TiB₂ stabilized closed cell aluminium alloy composite foams, Mater. Des, 2016, 101, 245–253
14. Jinyong Zhang., et all.Microstructure and properties of *insitu* titanium boride (TiB)/titanium (Ti) composites, Mater.Sci. Eng: A, 2015, 648, , 158–163

15. Reddy, J.N., An Introduction to the Finite Element Method, third ed. MicGrawHill, Singapore, 2006
16. Rajaravi, C., et al. Comparative Analysis of Al/TiB₂ Metal Matrix Composites in Different Mould Conditions, J. Adv. Mic. Res, 2015, 10260–264
17. Christy, T.V., et al. A comparative study on the microstructures and mechanical properties of Al 6061 alloy and the MMC Al 6061/TiB₂/12%. J. Min. Mater. Cha. Eng, 2010, 9, 57-65
18. Alaneme, K.K., Aluko, A.O. Fracture toughness (K_{1C}) and tensile properties of as-cast and age-hardened aluminium (6063)–silicon carbide particulate composites, Sci. Iran, Tran. A: Civil Eng, 2012, 19, 992–996
19. Naresh, S., et al. Computational Analysis of Stress Intensity Factor for a Quarter Circular Edge Crack under Mode-I loading. Res. J. Eng. Sci, 2013, 2(7), 38-42
20. Karbalaee Akbari, M. Tensile and fracture behavior of nano/micro TiB₂ particle reinforced casting A356 aluminum alloy composites, Mater. Des, 2015, 66, 150–161
21. Śliwa, A., et al. Simulation of the microhardness and internal stresses measurement of PVD coatings by use of FEM, J. Ach. Mater. Manu. Eng, 2010, 43, 2
22. Shivakumar Aradhya, K.S., Mrityunjay, Doddamani, R. Characterization of Mechanical Properties of SiC/Ti-6Al-4V Metal Matrix Composite (MMC) Using Finite Element Method. Amer. J. Mater Sci, 2015, 5(3C), 7-11